SR 147

Special Report 147

CHEMICAL PROPERTIES OF SOILS AT MINE-TUNNEL DETECTION RESEARCH SITES, PUERTO RICO

Timothy J. Simpson
and
Richard P. Murrmann

June 1970

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

ACCESSION for	
CFSTI	WHITE SECTION ☑
DOC	BUFF SECTION ☐
UNANNOUNCED	☐
JUSTIFICATION	
BY	
DISTRIBUTION/AVAILABILITY CODES	
DIST.	AVAIL. and/or SPECIAL
/	

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Destroy this report when no longer needed. Do not return it to the originator.

CHEMICAL PROPERTIES OF SOILS AT MINE-TUNNEL DETECTION RESEARCH SITES, PUERTO RICO

Timothy J. Simpson
and
Richard P. Murrmann

June 1970

DA PROJECT 1J662708A462

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

PREFACE

This report was prepared by CPT. T.J. Simpson, Ph.D. (Soil Scientist) and Dr. R.P. Murrmann (Research Chemist). The authors are members of the Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL).

This report was technically reviewed by SP5 Stephen F. Ackley and Dr. J. Rinker, USA CRREL. It is published under DA Project 1J662708A462, *Barrier/Counterbarrier Research.*

CHEMICAL PROPERTIES OF SOILS AT MINE-TUNNEL DETECTION RESEARCH SITES, PUERTO RICO

by

T.J. Simpson and R.P. Murrmann

The need to consider the influence of environmental parameters on the response of detection devices to objects of military significance has become generally accepted. In addressing this requirement, Puerto Rico was selected as an area where, due to a wide variety in environmental conditions, a facility could be developed for mine-tunnel detection research with emphasis on subtropical and tropical conditions.

The U.S. Army Engineer Waterways Experiment Station, which maintains an environmental study group in Puerto Rico, has recommended about twenty sites for future development. In this site selection, the requirements associated with both long-term environmental effects research programs and performance appraisal of current and future generations of detection devices were considered. A general description has been given of the soil at each of the mine-tunnel detection sites.[8] A detailed analysis of the physical properties of the soils has been made by Waterways Experiment Station.* The results of the chemical analysis of the soils are given in this report. Knowledge of the chemical properties is expected to be useful in interpretation of the response of various detection devices to the soil at each site.

Soil samples were collected at each of the proposed mine-tunnel sites in May 1969 using a 3-in.-diameter auger. At the Laguna Joyuda tunnel site, samples were obtained at 1-ft intervals to a depth of 8 ft at 3 locations to characterize chemical variability. The remaining sites to be used primarily for mine detection research were sampled only at one location to a 3-ft depth. The field-moist samples were stored in plastic bags until chemical analysis at which time sub-samples were dried and ground to pass through a 2-mm sieve. The analyses performed and references to the corresponding procedures are as follows: cation exchange capacity,[5] exchangeable sodium ions,[2] exchangeable potassium ions,[2] exchangeable calcium ions,[2] exchangeable magnesium ions,[2] exchange acidity,[2] soluble salt conductivity,[2] pH,[2] carbonates,[1] organic matter,[1] organic carbon,[1] total nitrogen,[2] iron oxides.[1]

Before discussing the results of the chemical analyses, it seems worthwhile to review how soils develop so that differences in chemical properties can be better understood. The genesis of a soil depends upon the interrelationship between climate, vegetation, parent material, topography, and time. In a subtropical and tropical region such as Puerto Rico, most soils are formed by laterization which can be visualized as two separate processes, primary laterization and resilication.[3] Primary laterization is chemical weathering during which Na^+, K^+, Ca^{2+}, Mg^{2+}, and silica are depleted with a concurrent enrichment of the oxides of aluminum and iron in the soil.

Primary laterization occurs under conditions of high temperature and unusually high rainfall on extremely well drained soils. The clay mineral content of these soils is very low. They may be composed of up to 90% free Fe_2O_3 plus Al_2O_3. Under moderate rainfall and drainage conditions,

* Private communication, Mr. Warren Grabau, U.S. Army Engineer Waterways Experiment Station

the process of silication to be described below may occur simultaneously with the result that some soils contain the clay mineral kaolinite which has a low SiO_2/Al_2O_3 ratio of one, and up to 10% Fe_2O_3. Other chemical properties which typify the situations described above are a low cation exchange capacity, low percent base saturation, and a low pH.

Silication is a chemical synthesis process by which silica resulting from primary laterization combines with iron and aluminum oxides in areas where silica accumulates as a result of imperfect drainage. This situation may occur near the water table level in soil below a zone of primary laterization, or near the surface in low-lying areas where drainage is impaired. Silication can also occur when conditions of low pH and moderate rainfall exist but the total water supply is too low to allow the transport of soluble silica. In any event, the products of silication are clay minerals. Depending on the amount of silica available, the minerals formed may be either of the kaolinite type with a low SiO_2/Al_2O_3 ratio of one, or the montmorillonite type with a relatively high SiO_2/Al_2O_3 ratio of two. In the latter case, soils are characterized by a high cation exchange capacity, high percent base saturation, and a high pH, with a relatively low Fe_2O_3 content of less than 3%.

Although the rainfall and temperature regimes fit the requirements for laterization throughout most tropical and subtropical regions, soils other than laterite soils are common. For example, soils classified as podzolic owe their development to the fact that they have been steadily supplied with weatherable mineral matter by rapid geologic erosion. The base and primary mineral silica content of these soils exceeds that of lateritic soils even though the environmental conditions favor laterization processes. Any major deviation from the required interrelationship between climate, vegetation, parent material, topography and time can produce conditions favoring other soil types. In Puerto Rico, due to the wide diversity in environmental conditions, many of the 22 great soil groups found on a world wide basis are present. As illustrated in Table I,[8] 13 of these great soil groups are represented by the mine-tunnel detection sites.

The results of this investigation are compiled in Table II. The chemical properties of the soils, although not as obvious in the field as the physical properties, nevertheless vary over a wide range. This is illustrated in Table III where the extreme values for each chemical property of the surface soil at the sites are listed. Despite the wide range in values obtained for a given type of determination, the variability can be explained in terms of the processes of primary laterization and silication described earlier.

The cation exchange capacity (CEC) of a soil arises primarily from two sources. The crystal lattice of most types of clay minerals is negatively charged, mainly due to substitution of divalent cations such as Mg^{2+}, Fe^{2+}, Zn^{2+}, and Co^{2+} for Al^{3+} which is the primary constituent of the inner layer of 2:1-type layer silicates such as montmorillonite, and substitution of Al^{3+} or Fe^{3+} for Si^{4+} in the outer layer of both 2:1 and 1:1 layer clay minerals such as kaolinite. The negatively charged lattice which results is neutralized by exchangeable ions that are capable of undergoing exchange reactions with both inorganic and organic cations from the solution phase The negative charge is expressed quantitatively as the number of milliequivalents of negative charge per 100 grams of material. Most clay minerals have a CEC of 5 to 200 meq/100 g. The second source of exchange capacity is decomposed organic matter (humus) which has a CEC of 50 to 150 meq/100 g.

The degree to which the CEC of a soil is neutralized by basic exchangeable cations such as Na^{+}, K^{+}, Ca^{2+}, Mg^{2+} other than H^{+} and cationic forms of Fe and Al is termed percent base saturation. At low base saturation, acidic conditions (low pH) prevail, whereas basic conditions (high pH) are present at high percent base saturation. Other ionic constituents in soil solution include salts which arise from numerous sources including dissolution of soil constituents, fertilizer additions, and seawater. The variation in these chemical properties with climatic and soil conditions

Table I. Description of mine detection research sites.

Devel. priority	*Site name*	*Group classification*	*Physiographic classification*	*Surface texture*	*Parent material*	*Vegetation*
			Primary Sites (USA CRREL Research)			
1a	Laguna Joyuda	Laterite	Upland, deep	Clay loam	Serpentine rock	Sugar cane
1b	Lajas	Alluvial	River floodplain, poorly drained	Clay	Alluvium	Grass
1c	Isabela	Sand	Coastal lowlands, well drained	Sand	Coral, shells	Grass, palm
1d	El Yunque	Yellow podzol	Upland, medium deep	Silt loam	Cretaceous, tuff-aceous sediments	Tropical forest
2a	Florida	Yellow-brown laterite	Coastal plain, compact	Sandy clay	Limestone	Grass
2b	Salinas	Red prairie	Terrace and alluvial fans, compact	Clay loam	Cretaceous, tuff-aceous sediments	Sugar cane
2c	Manati	Alluvial	River floodplain, well drained	Silt loam	Alluvium	Sugar cane
3a	Sierra Bermeja	Rendzina	Upland, shallow	Clay loam	Limestone	Grass, shrub, cactus
3b	Pargue [illegible]	Half-bog	Coastal lowland, poorly drained	Loam	Coral, shells	Mangrove
4	Yauco	Chernozem	Terrace and alluvial fans, medium friable	Clay	Limestone	Sugar cane
5	Laguna Tortuguero	Yellow-brown laterite	Coastal plain, very friable	Sandy loam	?	Grass, palm
			Secondary Sites (USA CRREL Research)			
6	Rio Guayanes	Red prairie	River flood plain, well drained	Sandy loam	Granodiorite and quartz diorite	Grass
7	Rio Abajo	Lithosol	Upland, medium deep	Clay	Cretaceous, tuff-aceous sediments	Forest
8	Yaubauco	Wiesenboden	River floodplain, poorly drained	Sandy loam	Alluvium	Sugar cane
9	Sabana Hoyos	Brown laterite	Coastal plains, compact	Sandy clay	Alluvium	Sugar cane
10	Toro Negro	Red-brown laterite	Upland, deep	Clay loam	Cretaceous, tuff-aceous sediments	Forest
11	Llanos	Planosol	Coastal plain, compact	Loam	Cretaceous, tuff-aceous sediments	Grass, palm
12	Moca	Alluvial	River floodplain, poorly drained	Clay	Alluvium	Sugar cane
–	Rio San Patricio	Red-brown laterite	Upland, deep	Clay loam	Cretaceous, tuff-aceous sediments	Forest
–	Dorado	Alluvial	River floodplain, well drained	Silt loam	Alluvium	Sugar cane
–	Loiza	Alluvial	River floodplain, well drained	Silt loam	Alluvium	Sugar cane

corresponding to the processes of primary laterization and silication is given in Table IV. As expected on the basis of earlier discussion, conditions of upland topography, good drainage, high rainfall, and old landform lead to lower CEC, low percent base saturation, and low pH. Due to leaching conditions, the soluble salt content is low. The iron oxide content is enriched as a result of primary laterization. However, silication must also occur in these upland soils since kaolinite is present[1] and the iron oxide content is relatively low. The fact that montmorillonite is present[4] in the young, imperfectly drained soils supports the view that silication is the dominant process under these environmental conditions.

Table II. Chemical properties of soils at mine-tunnel detection research sites, Puerto Rico

Site name	Depth, feet	CEC, meq/100g	Exchangeable cations, meq/100g					pH	Salt conductivity, mho x 10^5	Carbonates, percent	Organic matter, percent	Organic carbon, percent	Nitrogen, percent	Iron oxides, percent
			Na^+	K^+	Ca^{2+}	Mg^{2+}	H^+(equiv)							
Laguna Joyuda	0-1	17.2	.05	.13	6.01	.43	17	5.0	22	.051	4.4	2.30	.172	5.81
	0-1	17.2	.05	.12	5.58	.40	14	5.0	22	.060	5.0	2.90	.164	5.62
	1-2	15.8	.05	.05	1.76	.51	15	4.6	12	.042	2.2	1.44	.108	8.55
	2-3	16.9	.04	.03	1.49	.65	12	4.7	12	.069	1.2	.67	.061	9.28
	3-4	15.8	.09	.03	.88	1.19	9	4.7	12	.066	.5	.37	.040	9.59
	4-5	13.5	.10	.03	.35	.91	9	5.0	<5	.039	.3	.27	.036	9.40
	5-6	17.8	.15	.03	.26	.65	11	5.1	<5	.060	.4	.30	.038	9.32
	6-7	15.2	.14	.03	.26	.43	11	5.0	<5	.039	.4	.26	.035	9.32
	7-8	14.7	.13	.03	.24	.40	10	5.0	<5	.054	.4	.25	.032	9.62
	0-1	25.1	.05	.16	3.95	.80	21	4.7	26	.033	5.2	2.90	.204	7.68
	0-1	24.4	.04	.20	4.30	.80	21	4.7	26	.051	5.3	2.92	.208	7.51
	1-2	18.0	.04	.10	2.85	.76	13	5.0	14	.048	2.8	1.54	.080	8.26
	2-3	14.4	.03	.05	2.85	.72	11	5.3	11	.054	1.7	1.05	.084	9.84
	3-4	14.4	.03	.04	2.72	.80	9	5.6	10	.066	.8	.63	.076	9.98
	4-5	12.1	.03	.03	2.10	.91	9	5.2	15	.072	1.1	.58	.064	10.32
	5-6	13.7	.02	.03	1.19	.83	10	4.9	12	.045	.8	.55	.060	10.58
	6-7	12.7	.02	.04	.92	1.05	8	5.0	10	.054	.9	.54	.056	10.38
	7-8	11.8	.02	.02	.69	1.01	6	4.9	9	.063	.3	.54	.060	11.06
	0-1	17.8	.04	.25	3.69	1.01	14	4.7	36	.021	4.8	2.52	.216	6.56
	0-1	18.6	.05	.28	3.95	1.05	15	4.6	40	.039	5.0	2.62	.216	6.31
	1-2	16.7	.04	.05	3.07	.87	10	5.3	11	.054	2.3	1.21	.114	8.50
	2-3	16.9	.05	.03	2.63	1.05	6	5.8	<5	.042	.8	.46	.048	8.95
	3-4	12.1	.05	.03	1.93	1.09	5	5.1	<5	.048	.5	.27	.036	9.71
	4-5	15.2	.07	.03	2.41	.83	5	5.4	<5	.081	.4	.27	.032	12.76
	5-6	15.2	.08	.04	3.07	.83	5	5.6	<5	.084	.2	.18	.030	9.14
	6-7	17.4	.07	.03	3.07	.76	3	5.6	<5	.090	.4	.15	.029	10.70
	7-8	10.5	.07	.03	3.16	.60	3	5.7	<5	.108	.4	.09	.024	8.86
Lajas	0-1	51.6	5.2	.68	36.2	16.2	9	6.3	400	.315	2.1	1.27	.104	2.63
	1-2	51.1	8.7	.57	33.8	18.8	7	6.7	600	.348	2.0	1.05	.076	2.38
	2-3	48.8	9.7	.50	30.0	18.2	4	7.2	675	.384	1.3	0.65	.052	2.38
Isabela	0-1	1.2	.11	.03	11.1	1.3	0	8.8	17	1.49	0.2	.86	.016	.17
	1-2	1.0	.10	.02	11.7	1.4	0	8.7	10	1.47	0.2	.41	.016	.35
	2-3	.9	.08	.02	11.2	1.3	0	8.7	9	1.47	0.2	.54	.016	.35
El Yunque	0-1	33.3	.23	.14	4.17	1.45	23	4.8	21	.045	10.8	4.54	.272	4.21
	1-2	30.5	.08	.08	.40	.43	14	4.8	<5	.039	11.6	5.50	.275	4.25
	2-3	25.4	.10	.05	.41	.51	20	4.6	<5	.030	5.7	2.88	.152	7.95
Florida	0-1	15.2	.23	.25	.59	.14	16	4.8	<5	trace	.8	1.53	.168	3.31
	1-2	18.1	.08	.08	.73	.12	16	4.5	<5	"	2.5	1.38	.112	5.49
	2-3	20.0	.10	.11	.21	.09	15	4.4	9	"	5.0	1.05	.088	6.55
Salinas	0-1	37.3	.47	.73	25.6	5.97	3	7.8	22	.417	2.5	1.15	.114	3.45
	1-2	35.1	.55	.68	25.6	6.85	4	7.6	13	.402	0.8	.38	.056	3.51
	2-3	30.5	.53	.62	27.5	5.97	2	7.7	25	.474	0.5	.21	.032	3.45
Manati	0-1	29.1	.19	.18	19.3	5.41	8	6.9	11	.33	1.5	.82	.076	4.26
	1-2	30.3	.16	.15	18.4	5.09	6	7.1	<5	.40	0.8	.41	.052	3.95
	2-3	27.0	.17	.15	18.4	5.09	6	7.2	<5	.40	0.8	.31	.036	3.80

Site name	Depth, feet	CEC, meq/100g	Exchangeable cations, meq/100g Na^+	K^+	Ca^{2+}	Mg^{2+}	H^+(equiv)	pH	Salt conductivity, mho x 10^5	Carbonates, percent	Organic matter, percent	Organic carbon, percent	Nitrogen, percent	Iron oxides, percent
Sierra Bermeja	0-1	34.6	.08	1.52	37.7	3.34	2	7.7	34	4.26	4.4	3.83	.24	1.16
	1-2	24.8	.14	.55	25.6	3.18	1	8.2	19	1.49	1.2	1.32	.06	2.22
	2-3	38.2	.21	.78	31.4	6.21	1	7.7	100	1.37	2.6	1.67	.16	2.13
Parquera	0-1	20.4	42.1	2.0	24.1	13.9	1	7.0	3000	4.41	4.6	2.45	.044	4.41
	1-2	11.8	31.1	1.9	14.0	10.0	0	8.2	1600	6.78	2.0	2.70	.048	6.78
	2-3	39.5	85.7	4.5	25.6	27.1	1	7.6	4000	3.76	6.8	3.59	.104	3.76
Yauco	0-1	51.6	.60	.91	43.5	7.7	3	7.3	70	.894	3.2	1.76	.18	2.74
	1-2	48.8	.61	.65	40.6	7.0	2	7.8	40	2.61	1.1	.67	.08	2.78
	2-3	33.3	.51	.47	32.4	5.1	0	8.1	35	5.31	0.9	.64	.044	1.43
Laguna Tortuguero	0-1	3.6	.08	.08	1.1	.54	2	5.9	11	.13	1.1	.61	.076	.88
	1-2	2.7	.07	.03	.72	.43	3	5.7	11	.11	0.3	.15	.044	1.02
	2-3	15.1	.34	.17	4.4	2.4	5	6.0	12	.16	0.4	.26	.064	2.57
Rio Cuayanes	0-1	16.7	.15	.16	9.5	.94	12	5.0	<5	.20	2.4	1.1	.11	1.25
	1-2	5.6	.15	.03	2.9	.25	9	5.1	<5	.18	.5	.23	.044	1.2
	2-3	3.4	.17	.03	1.5	.40	4	5.5	<5	.23	.3	.06	.022	.89
Rio Abajo	0-1	53.9	.15	.23	27.5	5.1	17	5.5	8	.213	3.6	2.17	.22	5.42
	1-2	47.2	.16	.18	18.4	4.0	20	5.1	<5	.138	2.5	1.47	.17	4.39
	2-3	46.6	.23	.20	11.0	2.3	20	5.1	<5	.138	1.3	.69	.08	5.87
Yaubauco	0-1	16.7	.15	.16	9.5	.94	6	6.1	14	.204	2.6	1.1	.10	1.25
	1-2	5.6	.15	.03	2.9	.25	1	5.8	14	.132	0.5	.23	.04	1.20
	2-3	3.4	.17	.03	1.5	.40	1	5.9	17	.114	0.1	.06	.03	.89
Sabana Hoyos	0-1	13.9	.03	.25	.88	.10	11	4.2	20	.045	1.9	1.0	.114	5.65
	1-2	13.5	.04	.27	.74	.11	10	4.3	20	.039	.9	.45	.080	5.58
	2-3	14.2	.03	.18	2.11	.25	9	4.8	15	.063	.7	.42	.080	7.29
Toro Negro	0-1	28.9	.06	.06	.14	.14	14	4.8	<5	.036	1.0	.58	.036	8.78
	1-2	33.3	.07	.05	.09	.16	16	4.8	<5	.060	1.9	1.0	.060	7.85
	2-3	33.3	.09	.09	.26	.32	19	4.6	5	.078	4.7	2.5	.148	8.23
Llanos	0-1	19.3	.26	2.54	7.6	4.3	6	5.9	160	.126	5.2	2.57	.275	2.36
	1-2	12.3	.26	2.75	5.8	4.3	3	6.0	200	.108	2.8	1.36	.144	2.33
	2-3	17.5	.49	3.78	2.4	2.15	5	5.7	165	.042	0.6	0.54	.068	4.50
Moca	0-1	50.0	.27	.36	28.0	3.82	12	6.0	12	.225	2.8	1.65	.132	2.81
	1-2	49.5	.51	.34	30.0	4.78	9	6.3	22	.231	1.9	.95	.108	2.72
	2-3	41.7	.72	.25	21.7	4.94	8	6.5	45	.208	0.9	.38	.048	3.68
Rio San Patricio	0-1	39.3	.12	.20	.78	5.33	26	4.8	<5	.10	0.5	.21	.032	4.92
	1-2	44.4	.10	.18	.51	8.84	29	5.0	<5	.11	0.2	.83	.020	4.46
	2-3	42.4	.13	.16	.80	11.9	23	5.3	<5	.15	0.4	.56	.024	4.25
Dorado	0-1	35.3	.22	.20	15.9	5.17	15	5.0	16	.447	2.6	1.49	.124	3.58
	1-2	32.0	.23	.21	21.7	6.77	8	6.1	11	.471	2.3	1.33	.104	5.49
	2-3	30.3	.19	.17	16.9	7.56	5	6.7	10	.417	1.4	.72	.060	3.41
Loiza	0-1	26.1	.08	.38	6.01	1.12	16	4.4	18	.189	3.1	1.69	.155	2.51
	1-2	22.6	.12	.07	14.0	2.79	6	5.7	13	.285	2.1	1.0	.107	2.58
	2-3	22.2	.17	.07	14.0	3.58	5	6.3	16	.306	1.6	.79	.084	2.55

Table III. Range in chemical properties of surface soil (0-1 ft) at mine-tunnel sites.

Property	Units	Range Min	Range Max
CEC	meq/100g soil	1.2	54
Exchangeable Na^+	meq/100g soil	0.03	5.2
Exchangeable K^+	meq/100g soil	0.03	2.5
Exchangeable Ca^{2+}	meq/100g soil	0.14	44
Exchangeable Mg^{2+}	meq/100g soil	0.10	16.2
Exchangeable acidity	meq/100g soil	trace	26
Salt conductivity	mhos/cm $\times$ 10^5	<5	3000
pH		4.2	8.8
Carbonates	weight percent	0.04	4.4
Organic matter	weight percent	0.2	10.8
Organic carbon	weight percent	0.2	4.5
Nitrogen	weight percent	0.02	0.27
Iron oxides	weight percent	0.2	8.8

Table IV. Variation in chemical properties with climate and soil conditions.

Climate and soil conditions	Depth ft	CEC meq/100 g	% B S meq base/CEC	pH	Conductivity,** µmhos/cm	Iron oxides, %
Upland, good drainage high rainfall, old land- form (primary lateri- zation favored).*	1	21.0	28.4	4.9	10.4(5-22)	4.3
	2	20.0	23	4.85	9.0(5-20)	5.0
	3	21.0	26	5.0	9.0(5-15)	6.0
Imperfect drainage, low to moderate rainfall, young land- form (silication favored). †	1	35.3	73	6.5	22.0(8-70)	2.8
	2	30.8	76	6.8	14.3(5-40)	2.8
	3	32.7	75	6.95	25.5(5-100)	3.0

* Average of eight mine-tunnel sites: Toro Negro, Sabana Hoyos, Rio San Patricio, Florida, Laguna Tortuguero, Rio Guayanes, Laguna Joyuda, El Yunque.

† Average of the remaining sites. In some cases drainage was good; however, the landform was very young; i.e. recent alluvium at Dorado, Loiza, and Manati.

** Parguera and Lajas not included because of very high salt content. Parguera conductivity = 3000; Lajas = 600.

A number of soils contained significant amounts of carbonates. This condition, as illustrated in Table II by the Sierra Bermeja, Parguera, and Yauco sites, is typified by a high pH and the presence of relatively large amounts of exchangeable Ca^{2+} and Mg^{2+}. Since carbonates are water soluble, it is common to find a distinct physical discontinuity in calcareous soils caused by accumulation of carbonates near the permanent water table level.

The total organic matter content of the soils varied from almost zero at the Isabela site to more than 10% at the El Yunque site. At each site the amount of organic matter decreased with depth due to initial accumulation at the surface. Upon the addition of undecomposed organic matter to a soil, soil microorganism populations rise, ingesting the added organic matter to obtain energy.

If the added material has a carbon to nitrogen (C/N) ratio of about 25, both carbon dioxide and soluble nitrogen products are produced from the added organic matter at rates that will ultimately reduce the C/N ratio[7].

If the C/N ratio is as high as 50, free nitrate compounds originally present in the soil are removed during the decomposition process[7]. Highly decomposed organic matter (humus) is physically amorphous and chemically diverse with a stable C/N ratio of from 8 to 15. The C/N ratios from the mine-tunnel sites are summarized in Table V. A consideration of the carbon and nitrogen content of soil organic matter should be important in attempts to detect underground explosives based upon differences in carbon or nitrogen content. In addition, the types of biological processes occurring may influence the types of volatile compounds of nitrogen present which could interfere with trace gas detection methods.

Table V. Carbon to nitrogen ratio for surface soils at the mine-tunnel sites.

Site	*C/N Ratio*	*Site*	*C/N Ratio*
Laguna Joyuda	13.5	Rio Guayanes	10
Lajas	12.7	Rio Abajo	10
Isabela	43	Yaubauco	11
El Yunque	17	Sabana Hoyos	9
Florida	9	Toro Negro	14
Salinas	10	Moca	12
Manati	20	Rio San Patricio	7
Sierra Bermeja	16	Dorado	12
Parguera	60	Loiza	11
Yauco	10	Llanos	9.5
Laguna Tortuguero	8		

REFERENCES

1. Black, C.A. *et al.* (1965) *Methods of soil analysis, Part 2.* American Society of Agronomy, Madison, Wisc.,

2. Greweling, T. and Peech, M. (1965) *Chemical soil tests.* Cornell University Agricultural Experiment Station, Ithaca, N.Y.

3. Mohr, E.C.J. and Van Baren, F.A. (1959) *Tropical soils.* The Hague, Holland: N.V. Uitgeverij W. van Hoeve.

4. Murrmann, R.P. (1969) Mine and tunnel detection by trace gas analysis. USA CRREL Status Report, December.

5. Peech, M. (1945) Determination of cation exchange capacity. *Soil Science,* vol. 59, p. 25-38.

6. Roberts, R.C. (1942) Soil survey of Puerto Rico. U.S.D.A., Bureau of Plant Ind.

7. Russell, W.E. (1961) *Soil conditions and plant growth.* New York: John Wiley and Sons, Inc.

8. Simpson, T.J. and Murrmann, R.P. (1969) Description of soils at mine-tunnel sites, Puerto Rico. USA CRREL Special Report 144.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) U.S. Army Cold Regions Research and Engineering Laboratory Hanover, N.H. 03755	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
CHEMICAL PROPERTIES OF SOILS AT MINE-TUNNEL DETECTION RESEARCH SITES, PUERTO RICO

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)
T.J. Simpson and R.P. Murrmann

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 1970	8	8

8a. CONTRACT OR GRANT NO. b. PROJECT NO. DA Project 1J662708A462 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) Special Report 147 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT
This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire 03755

13. ABSTRACT
Soil at each of the proposed mine-tunnel detection research sites in Puerto Rico was analyzed. Samples were obtained at 1-ft intervals to a depth of 8 ft at three locations at the Laguna Joyuda tunnel site to determine chemical variability at the site. At the remaining 20 sites to be used primarily for explosives detection research, samples were obtained at only one location to a 3-ft depth. Analyses performed included cation exchange capacity, exchangeable ions, exchange acidity, pH, salt conductivity, carbonates, organic matter, organic carbon, nitrogen, and free iron oxides. The variation in results observed from one site to another could be explained in terms of primary laterization and silication, two soil formation processes which occur in subtropical and tropical environments.

14. KEYWORDS

explosives detection
mine detection
research sites
soil chemical properties
tunnel detection

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified
Security Classification